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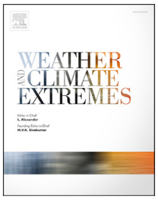

Extreme temperature differences in the city of Lahti, southern Finland: Intensity, seasonality and environmental drivers

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ABSTRACT

The extremes of month-specific spatial temperature differences were studied for a first time in the high-latitude city of Lahti and its surroundings in southern Finland. During the 2-year observation period (6/14–5/16), the largest momentary temperature difference, 11.1 °C, was detected in February, and the smallest, 6.2 °C, in April. The impacts of various environmental factors during the extreme situations were estimated by site-specific analysis of the warmest and coldest observation sites and a stepwise multiple linear regression model including all the 8 observation sites. The extreme temperature differences were characterised by inversions especially in winter and spring, the warmest site being the hill-top location in Kivistönmäki. In summer the role of urban heating was more apparent, and the temperature was the highest in the relatively low-lying city centre. In autumn the heating impact of the relatively warm Lake Vesijärvi caused the largest temperature differences with harbour as the warmest site. The weather during all of the momentary extreme situations was calm and in the majority of the situations also clear. The impact of cloud cover was less critical than that of wind speed in reducing spatial temperature differences. The momentary extreme situations existed at night or at dawn, with one exception: only in January, during the cold weather period dominated by high pressure, the delayed break of inversion in the vicinity of Lake Vesijärvi caused the extreme temperature difference to exist in the afternoon, reflecting for its part the substantial stabilising impact of seasonal ice cover on Lake Vesijärvi.

1. Introduction

Spatial temperature differences have been studied with various time scales extending from momentary situations to long-term average conditions. The role of site-specific human-modified or natural environmental factors (e.g. land use, topography, nearby water bodies) affecting spatial temperature differences in a given area can have large seasonal and diurnal variation (e.g. Eliasson and Svensson, 2003; Kolokotroni and Giridharan, 2008; Giridharan and Kolokotroni, 2009). In addition to site-specific characteristics, weather has a remarkable impact on spatial temperature differences, temperature differences being principally largest during calm and clear weather (e.g. Klysik and Fortuniak, 1999; Erell et al., 2011). Consequently, the pre-conditions for large momentary temperature differences cover a wide range of situations.

As for the magnitude of various environment- and weather-driven local temperature differences, urban heat island (UHI) intensity can be over 10 °C (Oke, 1987; Wienert and Kuttler, 2005). Local winds near water bodies have been reported to generate spatial temperature differences of similar magnitude between coastal and inland areas (Kuwagata et al., 1994). In hilly or mountainous areas, topography-enhanced inversions and related cold air pooling can cause temperature differences of over 15 °C within short distances (Pepin et al., 2009). In reality, spatial temperature differences can seldom be comprehensively defined to be caused by a single affecting factor only, but there are many of those involved.

The impact of environmental factors on temperatures has been estimated with various statistical methods, especially with different regression techniques (Hart and Sailor, 2009; Yokobori and Ohta, 2009; Ivajnšič et al., 2014). Development of remote sensing methods and better availability of geographic information system (GIS) datasets have increased GIS-based local climate research during last decades (e.g. Roth et al., 1989; Chapman and Thornes, 2003; Peeters, 2016). Compared to more sophisticated physical models, GIS based methods have proved to be cost-effective options to analyse and represent urban climate as a spatially continuous phenomenon (Szymanowski and Kryza, 2012; Heusinkveld et al., 2014), thus lowering the threshold to utilise local climate data in urban planning (Walther and Olonscheck, 2016). Compared to pure geometric spatialisation algorithms, such as inverse

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distance weighting (IDW), regularized spline with tension (RST) and ordinary kriging (OR), the methods that take account of the environmental factors around the observation points, often give more realistic spatially continuous temperature surfaces. The difference is highlighted in study areas with sparse or spatially uneven observation network and large spatial variability in land use, topography, vegetation and other relevant temperature modifying environmental factors. Temporally, the methodological difference is emphasised, when spatial temperature differences are large, e.g. during inversions or strong UHIs (Szymanowski and Kryza, 2009; Hjort et al., 2016; Aalto et al., 2017; Hsu et al., 2017). Many cities still have only few weather observation sites in their area and immediate neighbourhood, which sets a high challenge and demand for the development of sophisticated and cost-effective methods to produce spatially continuous temperature maps from point observation data to be utilised in versatile aspects of city planning (Liu et al., 2017; Sillmann et al., in press).

The extreme events of spatial temperature differences are relevant particularly from a health perspective and connected urban planning viewpoint. Strong UHIs worsen summer-time heat stress in urban areas. As an UHI is typically most pronounced during calm weather when atmospheric mixing is weak, its negative health impacts are often enhanced by poor air quality. Higher urban temperatures also promote the formation of secondary pollutants such as ozone (O_3) (Solecki et al., 2004). Regarding topography, inversions and connected poor atmospheric mixing also remarkably increase the probability of health-risky air quality events especially in cities that are located in valleys (e.g. Baumbach and Vogt, 1999; Wallace et al., 2010; Silcox et al., 2012). During extreme temperature difference situations in winter, slippery conditions can have substantial spatial variation, setting a challenge for road maintenance both in cities and their surroundings (e.g. Gustavsson, 1990; Riehm et al., 2012). The water-body driven local climatic extremes manifest themselves especially in human comfort questions. E.g. in summer, the daytime cooling effect of nearby water bodies can essentially improve thermal comfort in coastal zones (Saaroni and Ziv, 2003).

Better knowledge on the timing, spatial structure, preconditions and environmental drivers of extreme temperature difference situations gives more tools for sustainable urban planning, and supplements the information gained from long-time average temperatures for planning purposes. So far, especially UHI oriented local climate research has been livelier in low latitudes, where heat-related adverse health impacts are a more concrete problem (Wienert and Kuttler, 2005; Gago et al., 2013). As a consequence of climate change, the health perspective is predicted to become more relevant also in high latitudes (Emmanuel and Krüger, 2012; Ward et al., 2016). The warming climate can also alter spatial patterns of winter-time freezing-melting cycles in cool climate regions. For cities to be better prepared, to increase local climate knowledge and to develop its cost effective modelling methods in a changing climate, more information is needed. In this study, extreme temperature difference situations are studied and modelled for the first time in the Lahti region, in order to broaden the scientific basis of relevant city-specific features affecting local climates in high latitudes in particular. The detailed aims of the study are to

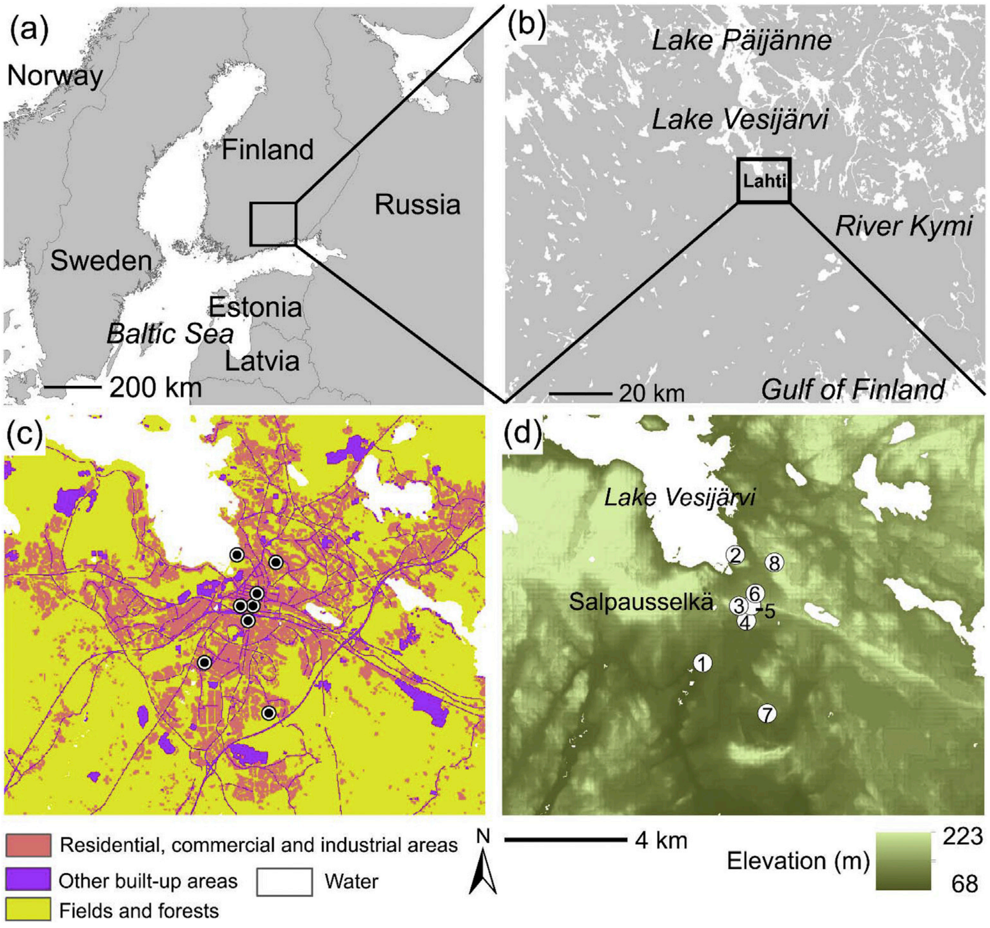

Fig. 1. The study area of Lahti in the southern Finland (a, b). The principal land use (c) and topography (d) with locations of the temperature observation sites. The city centre is in the surroundings of logger site 6. For more information on the logger sites, see Table 1.